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MEASUREMENT OF THE POWER HANDLING CAPABILITY OF
RESONANT SLOT ARRAYS

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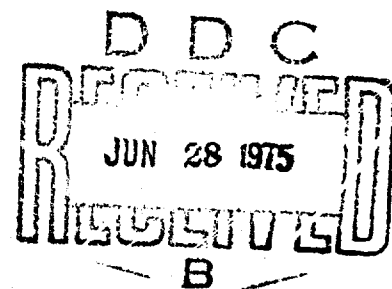
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Slot arrays	Metallic radome
Periodic surface	Resonant surface

20 ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report is a summary of an investigation to determine the incident power density which a resonant slot array can handle without causing permanant structural damage. The effect of altitude, varying the slot width, and also encasing the element in dielectric was measured for several different types of reactively loaded slots as well as circular slots. The effect of varying the element-to-element spacing in the array is explained. The significance of this research to the Air Force is that it provides guidelines for the design of periodic slotted surfaces as used in metallic radomes, subreflectors for cassegrain antennas, and space filters in general.

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FOREWORD

This report, Ohio State University Research Foundation Report
No. 3622-1, was prepared by the ElectroScience Laboratory, Department
of Electrical Engineering, The Ohio State University at Columbus, Ohio.
Research was conducted under Contract F33615-73-C-1173 of the Air Force
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Larry E. Carter, AFAL/WRP, was the AFAL Program Monitor for this
research conducted under Project No. 7633.

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I   INTRODUCTION

    Periodic slotted surfaces, when properly designed, have a well
defined resonant frequency band where they are essentially transparent to
incident electromagnetic energy. In this transmission band the surfaces
are obviously limited in the amount of incident power which they can
handle. If this limit is exceeded, the elements will break down (actually
arc across the slot), and in time this will cause permanent damage to the
surface. In most applications, these surfaces are subjected to high
incident power densities only in their transmission band. This, along
with the fact that higher incident power is required for breakdown, makes
their out-of-band performance unimportant. The purpose of this investigation
was to determine just how much power a surface could take (in its trans-
mission band) before breakdown occurs.

    The change in power handling capability of a single element as a
function of slot width, shape of the element, and atmospheric pressure
was determined. The effect of encasing the element in dielectric was
also investigated. From these measurements the maximum power density which
an array with a square lattice structure could handle was calculated using
methods developed by Munk, et al.[1].

II.   EXPERIMENTAL SETUP

    It has already been discussed in detail [2] how a single slot mounted
in a waveguide can be used to simulate an infinite periodic array. Such a
setup was used in this investigation to determine the breakdown level of
various slot configurations all of which had been chemically etched on
copper-clad RT/duroid, type 5870 stripline material (.003" thick copper
bonded to a substrate of .031" thick fiberglass-reinforced Teflon.) The
experimental system is shown in Fig. 1. The 4J52 magnetron which was used
as a power source was triggered by a high power audio oscillator which
also provided a synchronizing signal to the oscilloscope. The magnetron
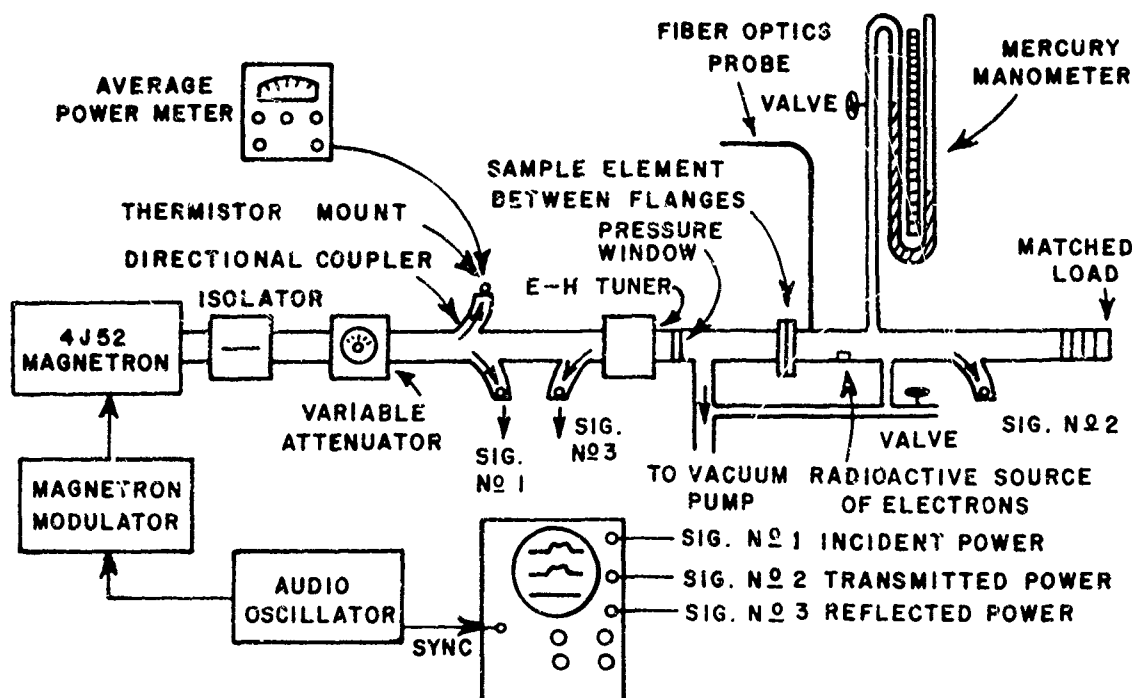
Figure 1. Experimental System Used To Determine
Breakdown Level Of Slots.

was connected to the rest of the system through a ferrite isolator to
protect it from power reflected by the sample under test. The variable
attenuator was used to adjust the amount of power incident on the sample.
Next to the attenuator were three directional couplers; the first two
coupled incident power from the magnetron to the oscilloscope (sig. #1)
and to the power meter. The third coupler provided a measure of the
reflected power (sig. #3) for the oscilloscope.

The operating frequency of the 4J52 magnetron was fixed at 9.375 GHz.
Because the transmission band of the loaded elements was very narrow and
therefore difficult to tune to the magnetron frequency, an E-H tuner was
inserted between the magnetron and the sample. This technique was used
only after the physical dimensions of the element had been adjusted so that
its resonance (as determined by inserting a slotted line and tunable
klystron just after the pressure window) was within one percent of the
magnetron frequency. When adjusted for maximum power transfer, the tuner
simply compensated for any mismatch caused by the slightly detuned sample.

2

The amount of power transferred to the load was the same as for a resonant condition and the impedance level to the right (Fig. 1) of the tuner was not affected by its presence. For these reasons the incident power measured at breakdown of the sample element was the same as that which would have been observed for a sample which resonated at exactly the magnetron frequency.

The next section of apparatus comprised the vacuum chamber in which the sample was placed. The dielectric sheet on which the sample element had been etched was held in place by compressing it between two waveguide flanges which had small recesses machined into them to hold the sample securely, while preserving electrical continuity in the guide walls. A small piece of radioactive material was placed in the chamber next to the element to provide a source of free electrons [3]. The pressure was controlled by the valve in the line leading to the vacuum pump, and monitored using the mercury manometer. Another directional coupler provided a measure of the transmitted power which was observed on the oscilloscope (sig. #2). Finally, the test apparatus was terminated in a matched load.

The power level at which breakdown occurred was determined by observing the oscilloscope display of the signals from the directional couplers marked sig. #1, #2, and #3 in Fig. 1. Before breakdown nearly all the power incident on the sample element was transmitted. After breakdown a large amount of power was reflected, with a corresponding decrease in the power being transmitted. The incident power was slowly increased until the oscilloscope display showed breakdown and this power level was read from the power meter (average indicating), with a correction factor added for the attenuation of the directional coupler. To insure that the breakdown which the oscilloscope display indicated was that of the element and not some other part of the system, the waveguide was probed with a fiber optic through which the bluish glow of the arc across the element was visible.

3

The pulse width and repetition rate used to modulate the magnetron output are important not only because they are required for the calculation of peak power, but also because they effect the power required for breakdown [4]. The pulse length was 0.5λ sec and the repetition rate was 1000 Hz for all the measurements presented in this report.

III. RESULTS

Using the technique developed in [1] and the data measured for a single element in the waveguide system, the maximum peak power handling capability as a function of atmospheric pressure was calculated for an array of each element tested. Measurements were taken for five basic types of elements with four variations of each type. The basic elements were:

      i)   circular slot
    ii)   double-loaded slot
  iii)   type I   loaded Y
   iv)   type II   loaded Y
    v)   type III loaded Y.

The four variations on each basic type were:

      i)   narrow slot width element without paraffin coating,
    ii)   wide slot width element without paraffin coating
  iii)   narrow slot width element with paraffin coating
   iv)   wide slot width element with paraffin coating.

The results and full scale representations of the elements are shown in Figs. 2, 3, 4, 5, and 6. The horizontal pressure scale has also been converted to an equivalent altitude using a standard atmospheric table compiled by NASA [5]. Above each graph is a full-scale representation of the sample elements for which the data applies. The dimensions given for the slot widths are for the samples without a paraffin coating; the elements which were tested with the coating had a physically narrower, although electrically equivalent slot width.

4

NARROW SLOT ◯ WIDTH = 0.7 mm
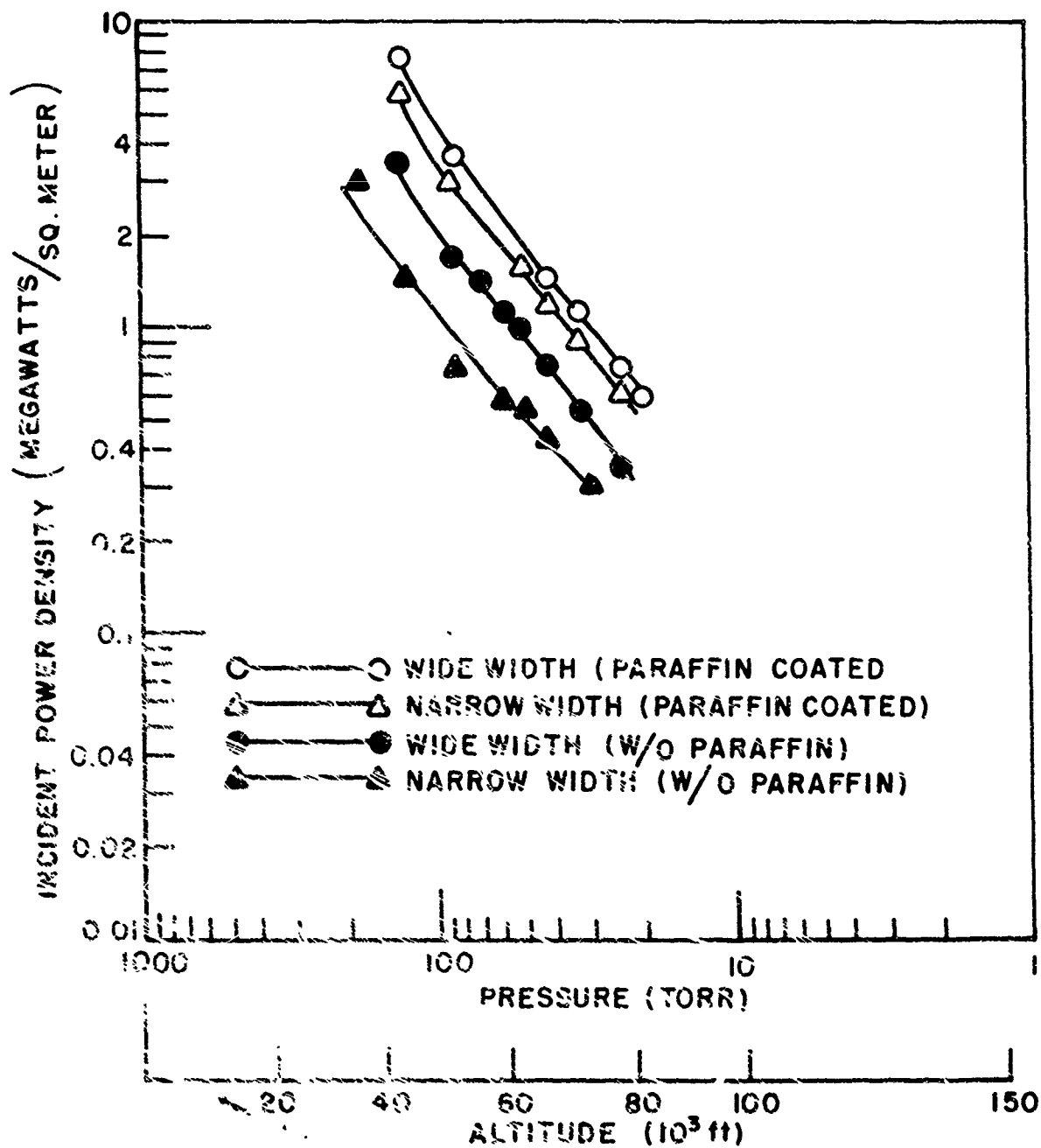
WIDE SLOT ◯ WIDTH = 1.3 mm

Figure 2. Incident Power Density Necessary For Breakdown Of
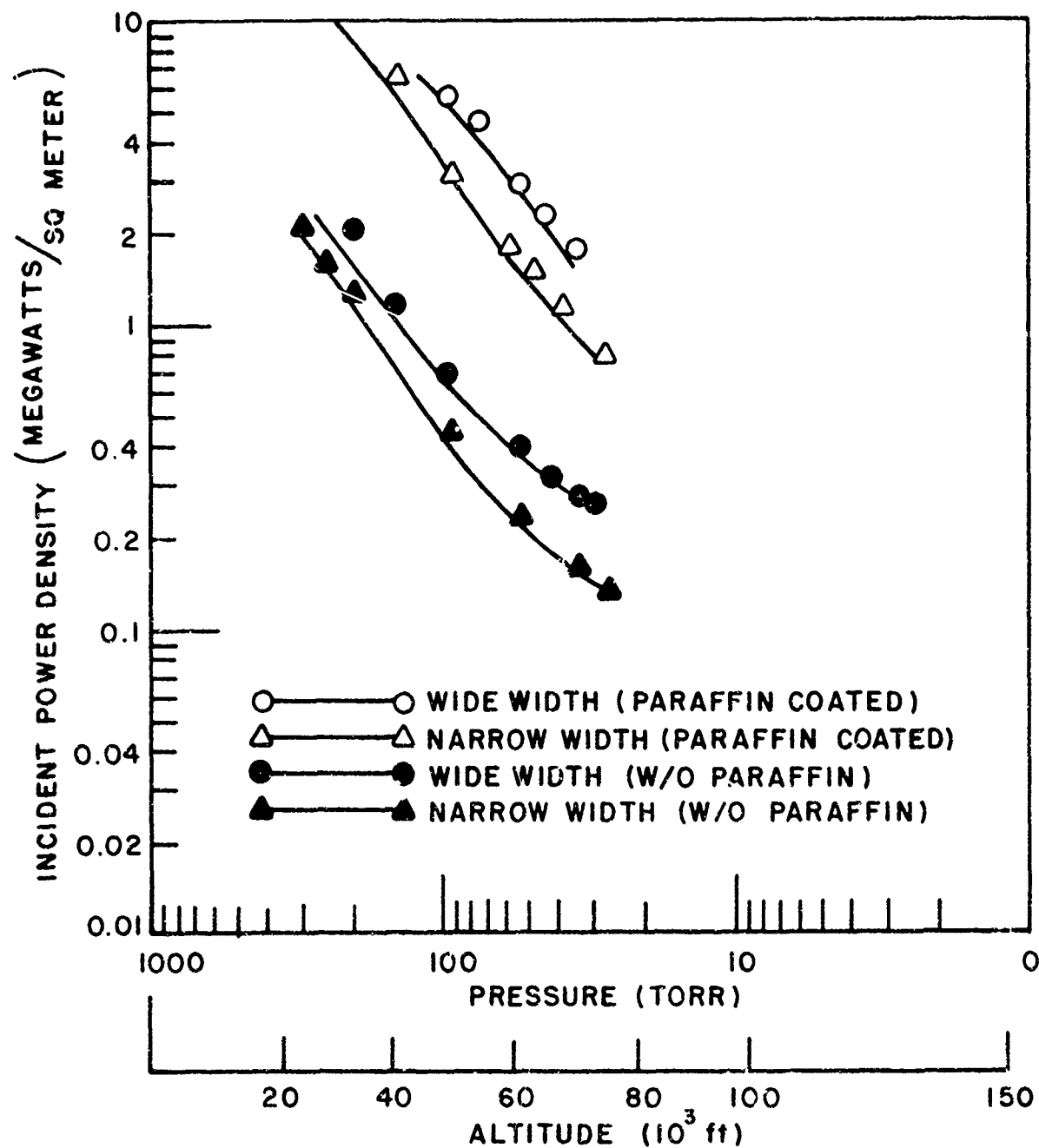Circular Slots In An Array With DX=DZ=0.5λ.

5

Figure 3. Incident Power Density Necessary For Breakdown Of
Double-Loaded Slots In An Array With DX=DZ=0.35λ.

6

NARROW SLOT ⟨⟩ WIDTH = .50 mm

WIDE SLⁿ ⟨⟩ WIDTH = 1.25 mm

Figure 4. Incident Power Density Necessary For Breakdown Of
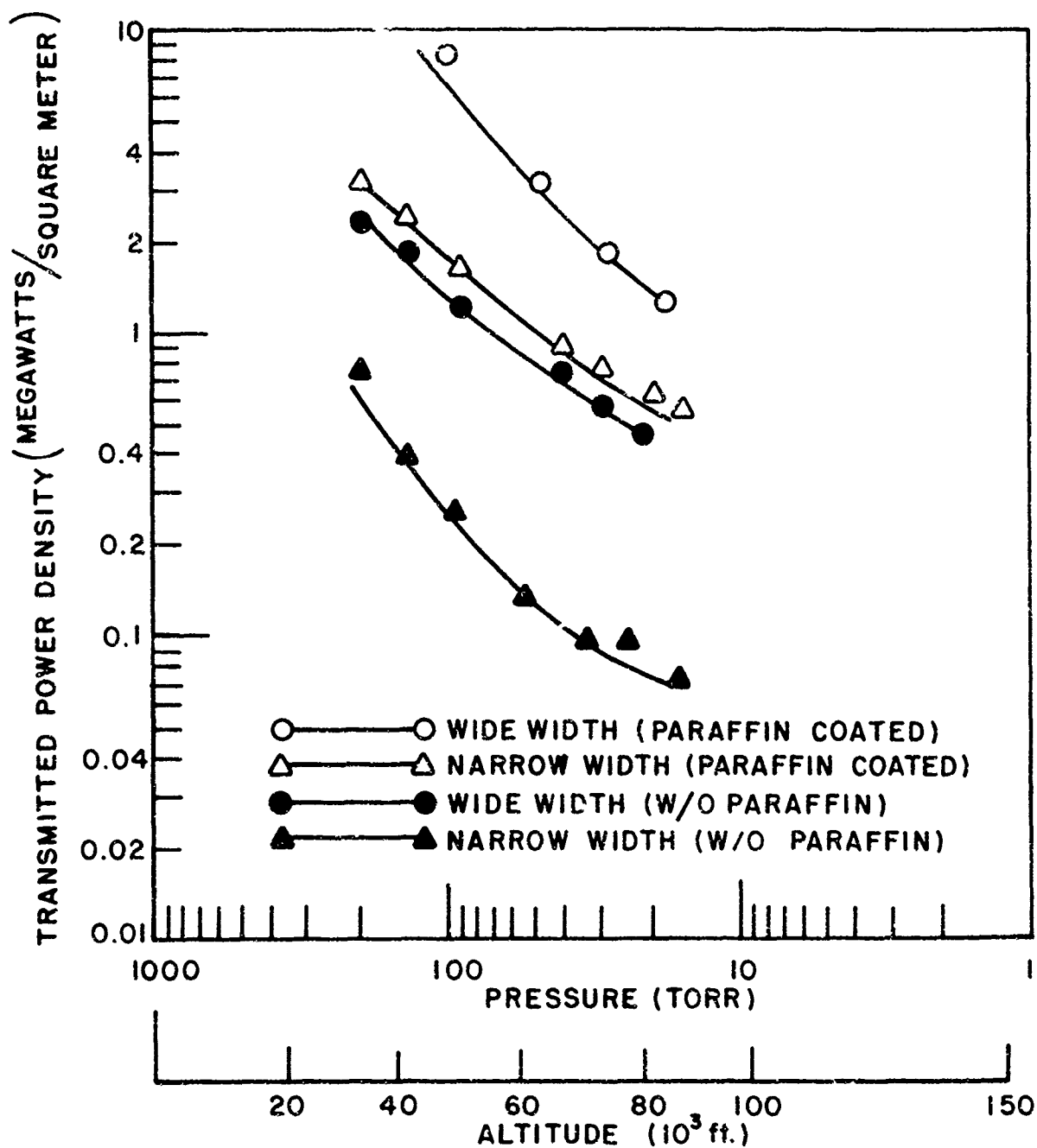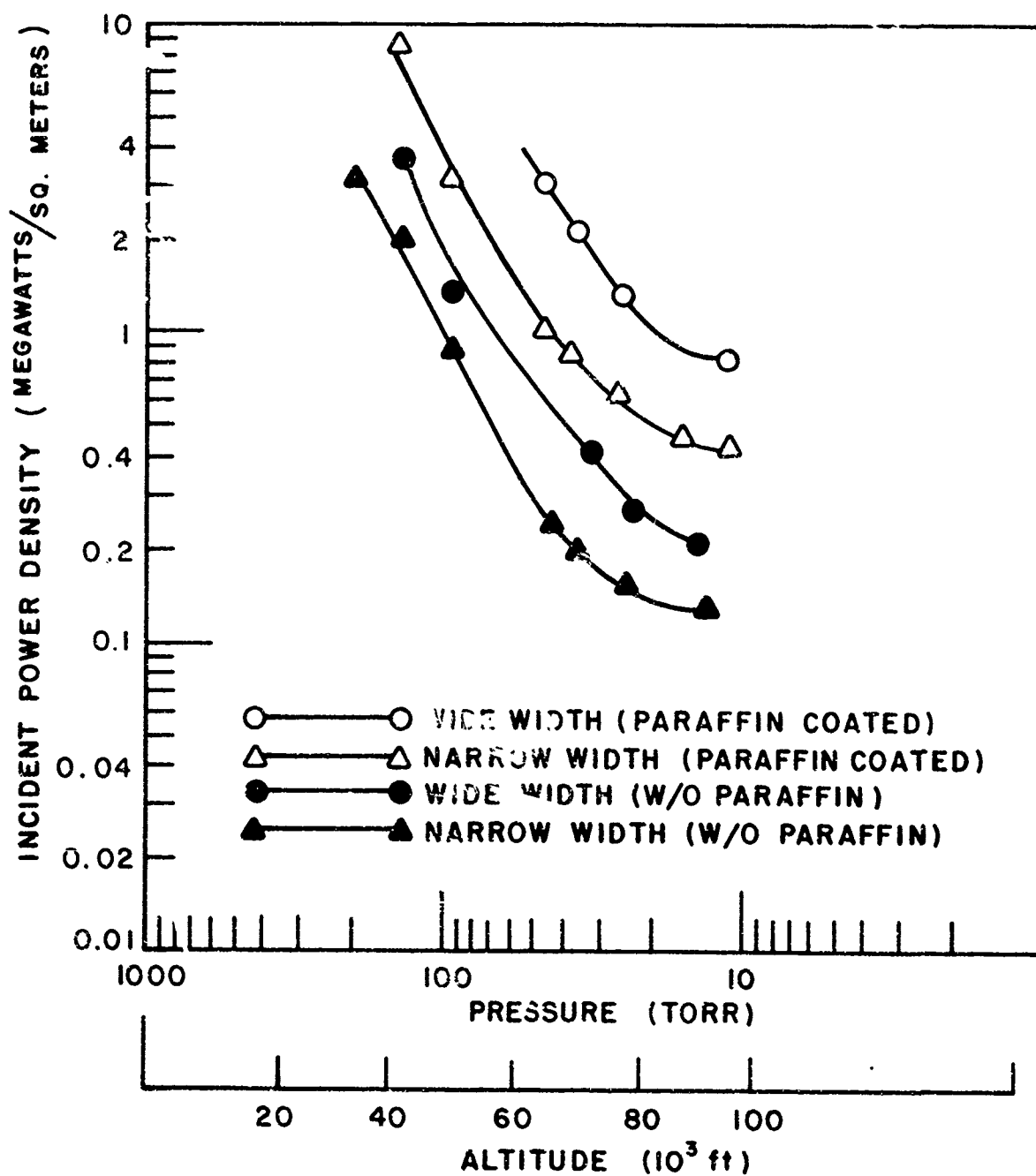Type I Loaded Y's In An Array With DX=DZ=0.35λ.

7

Figure 5. Incident Power Density Necessary For Breakdown Of
Type II Loaded Y's In An Array With DX=DZ=0.35λ.
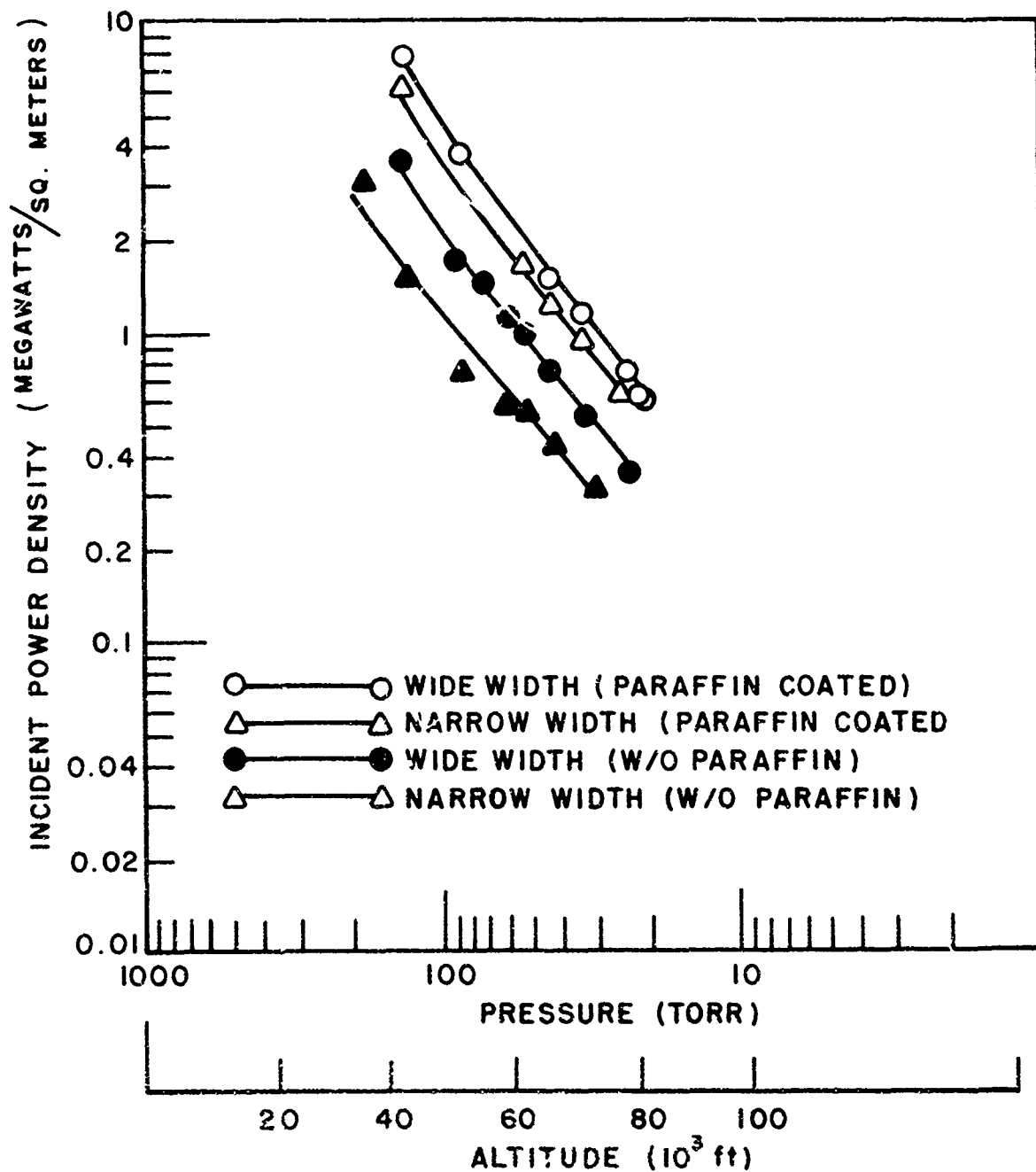
NARROW SLOT ⅄ WIDTH = 0.70 m

WIDE SLOT ⅄ WIDTH = 1.25 mm

Figure 6. Incident Power Density Necessary For Breakdown Of
Type III Loaded Y's In An Array With DX=DZ=0.35λ.

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It should be noted that the element-to-element spacing in the arrays for which the calculations were performed was not the same for the circular slots and the four types of reactively lo ded slots. For the circu'ar slot array, DX = DZ = 0.5λ. where DX and DZ are the element-to-element spacings in the X and Z directions, respectively, with the array situated in the X-Z plane. For the reactively loaded type slots, DX = DZ = 0.35λ. Because the circumference of the circular slots must be approximately equal to λ at their resonant frequency, they can not be spaced more closely than approximately .5λ in an array. The geometry of the reactively loaded slots on the other hand, allows them to be much more closely spaced than the circular ones. In most practical applications, the reactively loaded slots will be spaced less than .5λ apart to assure that the resonant frequency will be well away from the grating lobe frequency even as the angle of incidence on the array increases. The spacing of .35λ has therefore been chosen as a reasonable one for the calculations involving the reactively loaded samples. Quantitatively, the maximum incident power density which an array can withstand before breakdown is inversely proportional to the product of DX and DZ squared [1]. It is therefore easily seen that decreasing the element-to-element spacing will yield a significant incree in the power handling capability of the array.

Looking at Figs. 2, 3, 4, 5 and 6 it is apparent in every case that increasing the slot width of the element substantially increased the power handling capability of the array. This observation is easily explained since for a given incident power density, the voltage induced across a particular type of slot will be constant while the electric field in the slot will vary inversely with the slot width. This decrease in electric field strength as the slot width is increased allows the wide elements to withstand a higher incident power density before they break down. It is also clear from the figures that coating the elements with paraffin significantly increased their power handling ability. This is to be expected since any dielectric has a higher breakdown voltage than air. The change in transmission properties caused by encasing an array in dielectric has been investigated by Munk and Luebbers [6][7].

In general sharp edges and corners on the elements will cause high
field concentrations and lower power handling capability. With this in mind
the type II and type III loaded Y's are an attempt to create n element with
the transmission properties of the type I loaded Y, but with a higher power
handling capability. The approach taken was to put circles on the ends of
the type I element to form the type II and III elements. It is interesting
to note that, despite the fact that the type II loaded Y's had narrower
slot widths than the corresponding type I and III slots, they exhibited
just as high a breakdown level as the type I and III elements. This in-
dicates that they must have an inherently higher power handling capability.

IV. CONCLUSIONS

Intuitively, circular slots should be able to handle the most power
before breaking down because of their smooth shape. However, it has been
shown that when the effect of array spacing is taken into account, certain
reactively loaded slots (the double-loaded and the three types of loaded
Y's) can actually out-perform circular slots. Circular slots suffer
this handicap because their physical size preven them from being packed
more closely than 0.5λ. It has also been shown that increasing the width
of the slot, coating the element with dielectric, and properly shaping the
high potential areas will increase the power handling capability of an
element.

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[2] Ibid, pp. 6-11.

[3] A. D. MacDonald, Microwave Breakdown in Gases, John Wiley and Sons, New York, 1966.

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